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NRL Report 6611
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**Acceleration and Velocity Processing
of HF Radar Signals**
[Unclassified Title]

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NRL Report 6611

Acceleration and Velocity Processing of HF Radar Signals

[Unclassified Title]

J. E. McGEUGH AND G. K. JENSEN

*Radar Techniques Branch
Radar Division*

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ABSTRACT
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When determining the design of the signal processor, the overall radar problem must be considered in order to achieve optimum radar performance. The choice of a signal processor type for a high-frequency, over-the-horizon, pulse-doppler radar is particularly important because it must perform maximum signal enhancement to detect and observe very small signals buried in noise and, simultaneously, extract the maximum target information. Although many factors influence the design, this report is primarily concerned with the effect of target acceleration on the performance of the signal processor. Since targets of interest include guided missiles as well as aircraft, provision for acceleration and velocity processing should be included to insure that maximum sensitivity and velocity resolution will be available for both accelerating and constant velocity targets.

Examination was made of how target acceleration degrades performance in a simple velocity analyzer and also the method of providing essentially maximum sensitivity and velocity resolution for accelerating targets by an acceleration processing technique of spectral compression. Actual results obtained with a limited, 12-acceleration gate, acceleration and velocity signal processor confirm that full system sensitivity and velocity resolution are provided for accelerating and constant velocity targets.

In considering the advantages made possible by inclusion of acceleration processing, it is concluded that an acceleration and velocity signal processor using the spectral compression technique is highly desirable for a high-frequency, over-the-horizon, pulse-doppler radar.

PROBLEM STATUS

This is an interim report on the problem; work on other phases of the problem is continuing.

AUTHORIZATION

NRL Problem R02-42
USAF MIPR (30-602) 64-3412 to NRL dated Mar. 26, 1964

Manuscript submitted July 10, 1967.

ACCELERATION AND VELOCITY PROCESSING
OF HF RADAR SIGNALS
[Unclassified Title]

INTRODUCTION

A study of the overall radar problem is necessary before selecting the operating parameters and the equipment design for each component of an overall radar system. This preliminary study is particularly essential in the case of the signal processor for the high-frequency (hf), over-the-horizon (OTH) radar, where signal levels of desired targets may frequently be buried in noise, and significant gain in signal-to-noise ratio (S/N) is necessary in these instances even for detection. An optimum signal processor is required which has sufficient capability to extract maximum target information for all required operating conditions and target characteristics. It is necessary, at the same time, that this processor should be capable of enhancing the quality of data obtained and the overall system sensitivity. Neither increase of transmitter power output nor increase of antenna gain is a suitable substitute for inadequate signal-processing capability, because the quality of the extracted data may not be thereby recovered. There is not necessarily sufficient capability in these areas to even recover the sensitivity required for detection. However, a hf, OTH radar does need the best in transmitter and antenna capabilities within the obvious restrictions, such as cost and size.

While many factors, such as propagation mode, noise, signal losses, and ambiguities, in combination with target characteristics, determine design and performance of signal processing equipment, this report is concerned with (a) the effect that target acceleration has upon the signal-processor performance, (b) a means by which optimum performance of the signal processing equipment may be achieved for accelerating as well as constant velocity targets, and (c) results that have been obtained by the implementation of such a system.

The term acceleration processing means the optimum signal processing of radar signals from accelerating targets as well as constant velocity targets. NRL became interested in acceleration processing when the hf, OTH radar was first suggested to be used for the detection and observation of guided missile launches. This hf radar, known as Madre, is a crosscorrelation, pulse-doppler type that takes advantage of a 20-second signal storage time and subsequent integration, that is primarily coherent, to improve its S/N and, hence, detection capability. It also possesses a high doppler resolution which may approach $1/\text{storage-time}$ or $1/20$ cps. Normally, in the primary output the system is operated with a doppler resolution of $3/8$ cps. The S/N processing gain, in combination with a very high transmitter average power of 100 kw and modest antenna gain, has achieved a system sensitivity that permits aircraft detection with excellent doppler resolution at long OTH ranges.

It was recognized that when observing missiles with their usual characteristic of sustained acceleration, the doppler frequency change during the integration period would be great enough to seriously degrade system performance. The substitution of a 100-linear acceleration-gate system for the signal processor was proposed as a solution to this problem. Its purpose was to provide full radar system sensitivity, full doppler resolution, and the new acceleration parameter. It was also capable of performing full signal analysis in real time. The proposal represented a considerable quantity of electronic hardware and a correspondingly large funding requirement. Thus, for economic reasons limited funding was provided (by ARPA) which would permit only the development

of a 12-gate acceleration and velocity signal processor, sufficient to determine its capability and suitability for use as a full system.

The limited version was developed and implemented by NRL then moved to the Chesapeake Bay Division (CBD) radar site where it has been operated with the hf radar for the past 2 to 3 years. Many useful data have been gathered during this period, but it still remains a limited system and suffers the consequences in its operation. The prime difficulty is that only a small portion of the signal analysis may be performed in real time, whereas the full system would allow full analysis in real time. It remains the only operating acceleration signal processor available to use so it continues to be used in a program intended to establish reliable means of target signature identification and OTH missile flight characteristic data.

Recent work on the acceleration problem has led to the initiation of a newer type, non-limited, real time acceleration and velocity signal analyzer. This analyzer has been made possible through the concept of a new type analog capacitor signal memory developed by Jensen.* The memory itself offers the possibility of greater dynamic range, by several orders of magnitude, over that of the present analog magnetic storage disk and is expected to achieve 100 db or more. It also eliminates the need of bulky mechanical units and associated driving power and control, and it allows independent store and readout rates. The greater flexibility has permitted the design of a far simpler signal-processing system. Furthermore, the size and weight of the memory unit which is a hybrid micro-electronic system, is a small fraction of the former disk memory. The analog capacitor memory is presently in the status of procurement through a contract awarded to Boeing Aircraft Company in the latter part of 1966. Delivery of the first memory plane is anticipated in Sept. 1967. This problem is funded by the U.S. Air Force.

THE BASIC ACCELERATION PROBLEM

The basic problem of the radar system degradation of performance due to target acceleration can best be described by reference to a simplified block diagram of the presently used doppler analyzer (Fig. 1). It is assumed that acceleration loss does not occur ahead of the signal processor and that all prior circuits are optimized. Doppler analysis could be performed either by a multiplicity of parallel doppler filters (as many as 3600 for each range bin) or by a single filter scanned across the doppler range in conjunction with a signal memory. Without judgment of the merits of either method, the diagram represents the scanning filter method.

Some pertinent operating conditions are: prf, 180 cps; pulse width, 240 μ sec; and magnetic memory disk rotational rate, 180 cps. Hence, there are 23 range bins which physically spaced about the disk recording track circumference. The input to the signal storage disk is the receiver bipolar synchronous detector output from which the low doppler frequency backscatter components have already been filtered. When a signal is present, it is in the form of the familiar butterfly pattern, where the delay from the transmitter pulse to the signal represents the delay to the target and return (range), and the cyclic rate at which the amplitude varies is the doppler frequency. To retain range information, the signal bandwidth is 4 kc. Samples are taken once for each range bin following each transmitter pulse with a very narrow sample pulse, and these samples are stored as analog recordings in the corresponding range positions around the disk. Samples from successive transmitter pulses are stored adjacent on the disk in each range bin, and it requires 20 seconds to fill the storage (3600 stored samples in each range bin).

*G.K. Jensen, "A Proposed Simplified Signal Processor for the Improvement of the Madre Radar" (Secret Report, Unclassified Title) NRL Report 6237, March 11, 1965.

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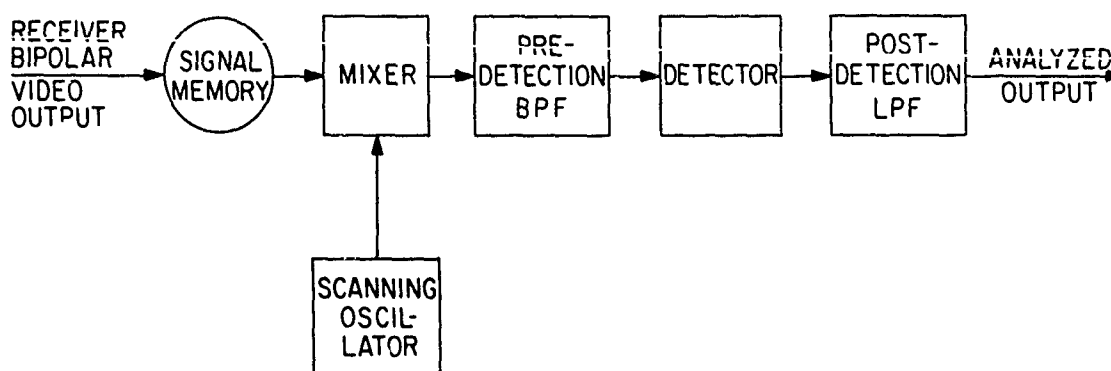


Fig. 1 - Doppler analyzer

An erase pulse removes the oldest stored information just prior to writing in new samples, an operation which is performed continuously. Readout is obtained from another pickup from the disk, a continuous operation also. Therefore, the 20-second stored signal is read from the disk in a time period of $240 \mu\text{sec}$ for each range bin, thereby, accomplishing a time compression ratio of 82,800:1. All doppler frequencies appear multiplied by this factor in the readout, so bandwidths may be widened correspondingly and analysis rates may be increased. This permits the analysis to be performed by a single scanned analysis filter in real time.

The mixer is used to offset the frequencies to an i-f where filtering is easiest. The oscillator input to the mixer is swept slowly in frequency so that a doppler frequency scanning effect is produced by the single filter. If the oscillator frequency is changed by the amount of the analysis filter bandwidth (BW) each revolution of the disk, continuous doppler coverage is obtained, and all range bins are thus examined at each equivalent doppler frequency. Actually, the oscillator step is only about $2/3$ of this BW per disk revolution to prevent loss at the overlap points. The number of required oscillator steps is determined by dividing the maximum unambiguous doppler frequency by the doppler resolution and increasing this quotient by the overlap factor. The result in the preceding example shown is about 360 steps. Total filtering is divided into two steps: one predetection, one postdetection. An envelope detector is located between filters. In order to supply coherent integration the full bandwidth narrowing must occur before detection. However, a number of sources have shown that reduction in S/N is slight if part of the bandwidth narrowing is done after detection, provided the detection occurs above unity S/N. In this analyzer the choice of a $3/8$ -cps equivalent doppler BW of the predetection filter instead of $1/20$ cps allows a number of full doppler analyses to be performed in real time, while the $1/20$ -cps equivalent postdetection doppler BW still allows most of the S/N gain to be realized. Some velocity resolution is sacrificed by widening the first filter.

A typical output of the doppler analyzer may be seen in Fig. 2. Horizontally, full scale represents a 90-cps doppler; the scale begins at 8 cps. Range information is also contained in this output, but it cannot be readily discerned unless the horizontal scale is greatly expanded. The top view is a photograph of the output obtained with a simulated target of constant velocity—in this case having a doppler frequency of about 24 cps. It may be observed that more than one vertical line appears for a single target as a result of the filter overlap just mentioned.

Notice the effect of supplying an input of exactly the same pulse amplitude and starting doppler frequency but with a simulated positive acceleration that causes a doppler

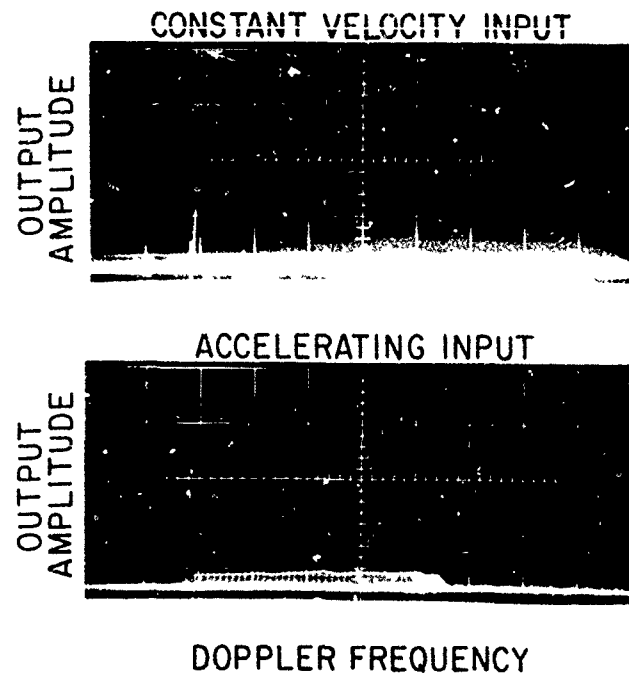


Fig. 2 - Doppler analyzer outputs for input signals from a simulated constant velocity target and a simulated accelerating target

frequency change of 36 cycles during the signal storage interval. A target acceleration of 2.7 g at a 20-Mc radar frequency would produce this signal. The amplitude of the output is shown to decrease approximately 10:1 or 20 db from that shown in the top view, even though the signal input amplitude remained the same. At the same time the signal energy is spread over the expected 36 cps. Some will say that this display is not a true doppler frequency spectrum. They are correct, but it does illustrate a coarse look at the frequency distribution of the signal energy. The true doppler spectrum contains components spaced by the prf, whereas this output for each line on the photograph is actually the total of all true spectral lines that fall within the predetection filter BW. Indicated lines are spaced by the period of the disk revolution. These two views are shown for inputs without noise, but it is not difficult to visualize that the upper signal could be easily detected in the presence of noise that would completely obliterate the signal in the lower view. Even if the signal amplitude is high enough to be discerned over noise, it will be displayed over a spread of 36 cps; hence, velocity resolution is lost. It may be said, in general, that some form of target acceleration-caused loss occurs whenever the stored signal is spread in doppler frequency by more than the equivalent doppler frequency BW of the predetection filter.

A good indication of velocity changes (acceleration) that may be expected for typical targets is obtained by reviewing the velocity-time characteristics of some of our own missile types. These data are plotted in Fig. 3. The curves represent plots of specific launches but are identified only by type to give a general idea of acceleration coverage required and should not be considered always typical of any named type. The doppler changes that occur in a 20-second storage interval may be scaled for any section of these curves. The change in velocity during this time interval may be expressed in target acceleration, possibly g's. For example, the Polaris A3 shows a maximum

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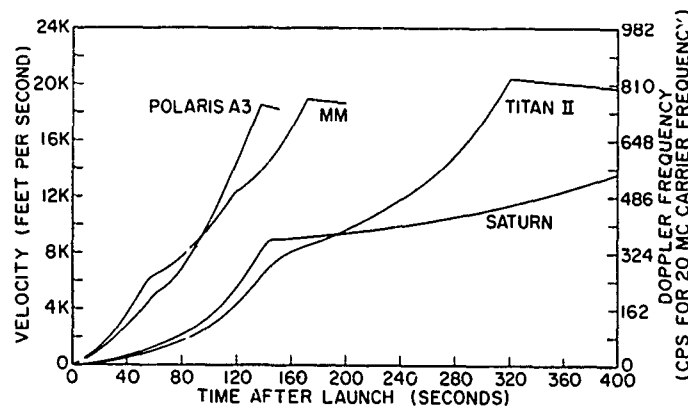
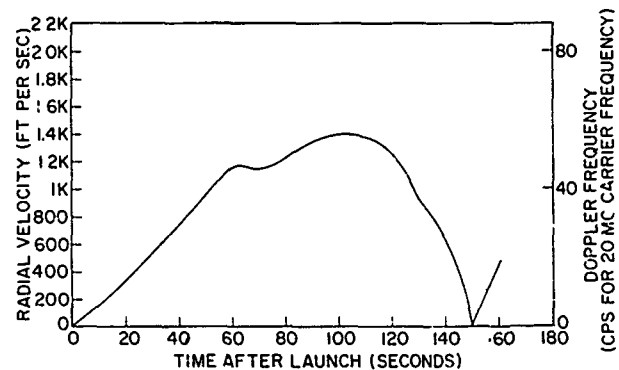


Fig. 3 - Velocity vs time characteristics of several missiles

Fig. 4 - Velocity vs time characteristic for an A3 Polaris missile launched from Cape Kennedy as viewed from CBD



velocity change of about 4000 ft/sec in a 20-second period which is an acceleration of 200 ft/sec² or about 6 g. This target acceleration causes a doppler change of approximately 160 cps in the same 20-second storage period, one that would result in a sizeable loss of sensitivity and resolution. Other time intervals might be similarly examined for doppler change. The antimissile missiles (AMM) show considerably greater acceleration but are not included here.

The velocities indicated in the previous figure showed values in the line of the missile trajectory. These values are modified in accordance with the geometry of the radar site relative to the missile flight path, and a quite different characteristic is obtained in the case where missiles launched from Cape Kennedy are observed from the CBD radar site. Here, at one point in the missile trajectory, during or near the period of powered flight, the illuminating ray path intersects the missile flight path at right angles. Figure 4 is a plot of this situation for an A3 Polaris, and it may be seen that the right angle condition occurs at 150 seconds after T-0, as indicated by zero radial velocity and resultant doppler. The vertical scales in this figure are just 1/10 the value of those of the previous figures because illumination during the interval shown is at a near 90° intercept angle. Actual operational conditions would be expected, usually, to be between the limits shown by these figures, but either limiting case could occur for specific intervals of time. It does seem from data available that an acceleration processor should be designed for at least 10 g target acceleration and, possibly, for as much as 20 g.

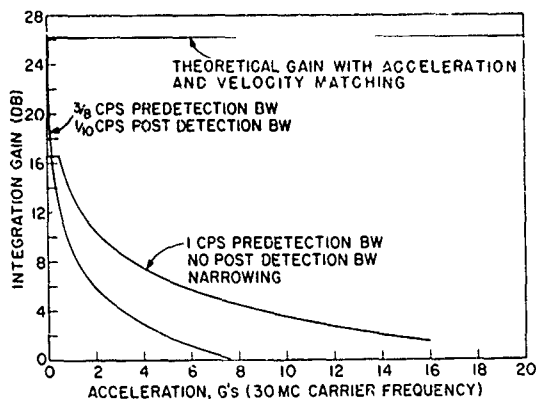


Fig. 5 - Integration gain vs target acceleration for an operating frequency of 30 Mc, signal storage of 10 sec, and prf of 45 cps

At first glance it might appear that the acceleration problem might be accommodated by widening the predetection filter bandwidth. This proposal is not a satisfactory solution even for low accelerations as indicated by Fig. 5. This particular figure is prepared for an operating condition of a prf = 45 cps and a storage time of 10 seconds. This condition sets the maximum possible integration gain, where, with full coherent integration, it could be 26.5 db, but a slight loss of a fractional db results from a 3.75:1 predetection to postdetection bandwidth ratio assuming a minimum output S/N of 13.5 db. It is seen that for the usual 3/8-cps predetection and 1/10-cps postdetection BW gain drops rapidly with increase of acceleration, where acceleration in target g's is indicated on the abscissa for a frequency of 30 Mc. (Although acceleration is not dependent upon carrier frequency, the acceleration-caused losses are dependent upon it.) Little improvement results from widening the predetection filter bandwidth unless the postdetection filter is also widened. When this is done, the S/N is thereby degraded by the ratio of the effective bandwidths, which here is from 1/10 cps to 1 cps or 10 db. A somewhat higher acceleration can then be accommodated without further loss until a point is reached where a 3-db additional loss per doubling of target g occurs. One loss not indicated by this figure is loss of velocity resolution. In either of these cases the velocity resolution will be no better than the spread of the stored doppler frequency.

Acceleration processing that makes use of a spectral compression technique can maintain integration gain at essentially the full indicated value (26.2 db) without suffering acceleration-caused loss, as shown by the horizontal line near the top of Fig. 5. The same process simultaneously provides full doppler resolution commensurate with the chosen predetection BW.

An example of signal amplitude gain and velocity resolution improvement by the spectral compression method of acceleration processing is shown in Fig. 6. Each view shows amplitude in the vertical direction, and all are calibrated to the same scale. The horizontal scale is calibrated in doppler frequency. An input signal simulates an accelerating target with a 36-cps doppler spread during the signal storage interval. The top view is the output obtained with the doppler analyzer and shows the signal spread over the full input doppler range (the display width is 90 cps) and reduced in amplitude, as would be predicted. The center view is the output obtained with spectral compression from the same input signal, with both vertical and horizontal scales the same as the top view. The signal amplitude is returned to nearly full magnitude, and the spectral width of the output is narrow as would be predicted. The lower view is shown only because of the difficulty in photographing the center view. The sweep width has been reduced in doppler frequency to intensify the signal and make it more easily viewed.

ANALYSIS
OUTPUT
WITHOUT SPECTRAL
COMPRESSION

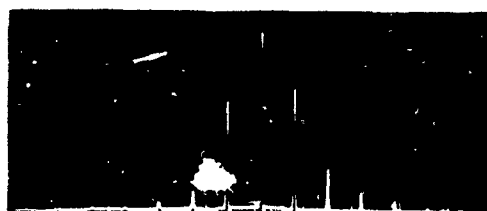


ANALYSIS
OUTPUT
SPECTRALLY
COMPRESSED



DOPPLER FREQUENCY (8.4 CPS/MAJOR DIV)

ANALYSIS
OUTPUT
SPECTRALLY
COMPRESSED



0.24 CPS

EXPANDED DOPPLER SWEEP

Fig. 6 - Analyzer output for simulated accelerating target that produces a 36-cps doppler frequency change during the 20-second storage interval (100 predetection bandwidths)

Fig. 7 - Analyzer input and output signals that show improved performance of an acceleration-gate output over a simple doppler analyzer output when the input signal is simulated for an accelerating target (1) input signal simulating an accelerating (2) same signal with noise added (3) output from simpler doppler analyzer for above input (4) output from acceleration gate channel for the same input

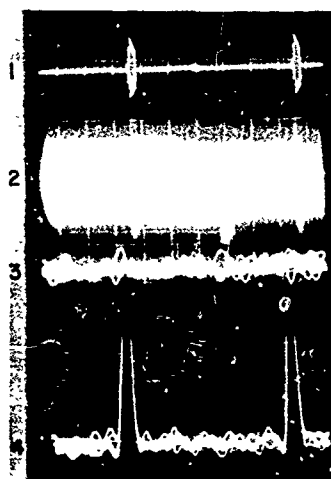


Figure 7 shows a similar result of signal enhancement but this time in noise. The top line represents the input pulse amplitude vs time at a 180-cps prf and contains a 36-cps equivalent doppler change (acceleration) during the storage period. The second

line is the input noise added to the above signal, which is then applied as input for the following two cases, as represented by lines 3 and 4. The noise bandwidth is the same as the equivalent 90-cps doppler bandwidth. Line 3 shows the output obtained from a constant velocity type (doppler) analyzer, and line 4 shows the output from an acceleration and velocity analyzer for the matched acceleration and velocity condition. The line 3 signal output, without spectral compression, is lost in noise. The output that takes advantage of spectral compression shows so large a signal output that it is many times the noise level. The difference in signal output level between lines 3 and 4 should be 20 db for this case, as verified by results.

SPECTRAL COMPRESSION TECHNIQUE AND DESIGN

The spectral compression method of acceleration processing has been implemented in the 12-acceleration-gate signal processor. Each of the 12 channels consists of an analyzer as shown in Fig. 8. This representation is basically the same diagram as the doppler analyzer, but the oscillator in this case has a second frequency modulation input. This second modulation is intended to provide a specific change of frequency vs time (or acceleration) as the signal from each range bin is read from storage. When this change of frequency vs time exactly matches a signal read from storage during a range bin interval, an output, equivalent to a constant doppler frequency, will be obtained from the mixer for that range bin interval. Since this signal may now be fully contained within the predetection filter bandwidth, a full filter response will result. Also, since the spectrum has been confined to a predetection BW at the mixer output, the velocity resolution will be just as good as for a constant velocity target.

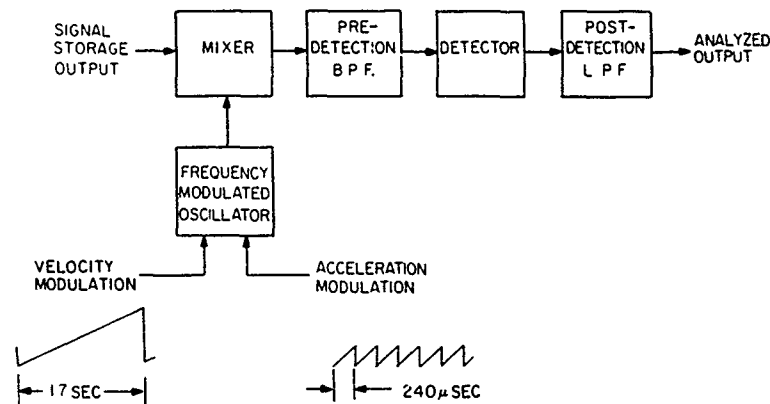


Fig. 8 - Acceleration-gate analysis channel

The selected acceleration modulation will exactly match only a single target acceleration (assuming a fixed radar frequency), but it is capable of providing a match in any range bin and at any starting doppler frequency because the acceleration modulation is a repetitive waveform. This channel is then a channel for only one specific acceleration. The c/sec^2 slope may be related to actual target radial acceleration when the operating frequency is given.

The required number of acceleration-gate channels for a selected acceleration coverage is determined by the predetection BW. When this BW is wider than the pulse spectrum for a constant doppler frequency, a tolerance is allowed in the closeness of slope matching of Δf vs time in order that the full mixer output spectrum may still be

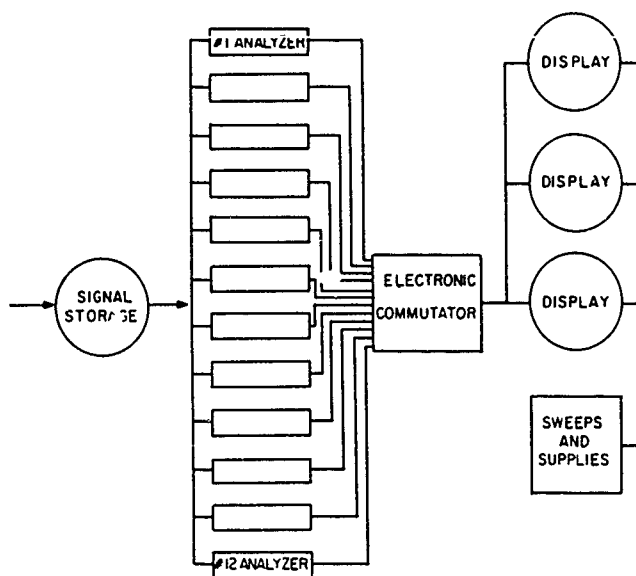


Fig. 9 - Twelve-acceleration-gate-signal analyzer

contained within the filter BW. Fewer acceleration-gate channels are required as the BW is widened, but velocity resolution and acceleration resolution are made poorer. A typical number of channels might be ± 120 for a $3/8$ -cps doppler resolution and a prf of 180 cps.

It may be noticed that both modulations to the oscillator occur simultaneously, but the doppler sweep repeats at a slow rate of about once per 1.7 seconds, while the acceleration modulation waveform repeats at a rate of about 4 kc/sec.

Although a channel labeled an acceleration gate infers a constant acceleration, a nonlinear function may be applied instead of the linear acceleration modulation waveform. This nonlinear function could be used to match a stored signal from a target whose acceleration changed within the store period. Such a modulation has been generated by the inclusion of diode networks that are capable of approximating a curve with 5 straight-line sections where break points may be selected, and individual section slopes are adjustable. While this method has been used successfully in nonreal time to match a specific characteristic, its real-time application would require a much larger number of channels than appears desirable.

Figure 9 shows that the acceleration gates may be combined in parallel by feeding the inputs in parallel and commutating the outputs electronically in synchronism with display sweep timing. Each of the 12 channels may be set for any acceleration, plus or minus, within the capability of the system, even including a zero or constant velocity channel. It has usually been most convenient to operate with the 12 channels set for a fan of 12 consecutive accelerations. These 12 accelerations may be operated in real time. Other accelerations must be covered by playback of magnetic tape on which the receiver output was previously recorded during the time of interest. A full acceleration system would perform the full analysis in real time.

Provision of suitable displays of target information is made more flexible by the addition of the acceleration parameter. It has been thought advisable to separate the displays of targets having accelerations above a chosen value from displays of constant

velocity targets. This separation allows a significant amount of background interference, such as meteors, aircraft returns, and constant frequency interference, to be removed from the accelerating target display and makes the observation of missile-type targets much easier. The zero acceleration or constant velocity displays would be provided separately. In the existing system this effect is accomplished by the choice of accelerations used in each of the 12 channels. Displays of velocity-range, acceleration-range, and acceleration-velocity were initially provided, but it was found, through experience in operating the equipment, that other displays are of equal or even more value. Some of these that should be added are: velocity-time, range-time, amplitude-time, and amplitude-velocity. The time scale allows time tracks, which add to operator confidence and detection capability, the latter providing a target spectral analysis.

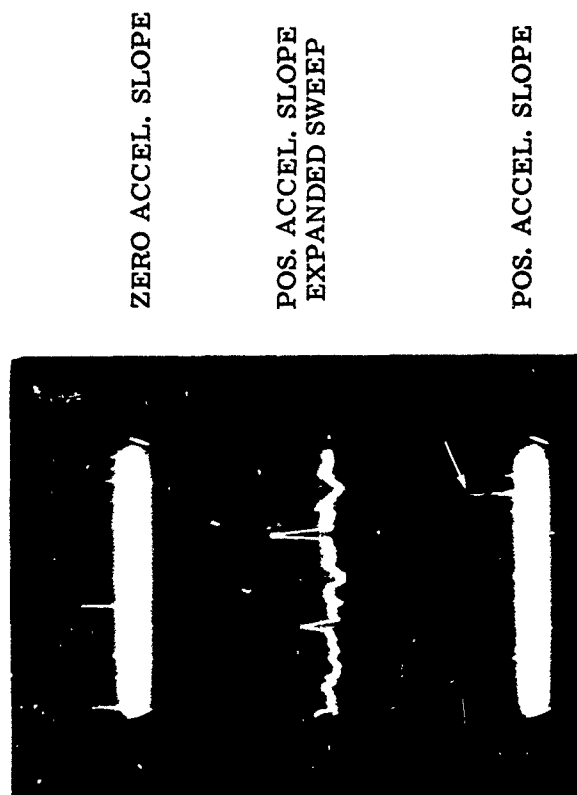
Collapsing losses must be avoided when using displays such as the velocity-range where 12 parallel channels supply the velocity output. Two approaches have been used. One approach makes use of auxiliary steps on the display sweeps to offset the spot position for each channel readout. This approach is possible whenever there are enough resolution elements on the display CRT, because offsetting may be accomplished in either direction. The other approach uses a threshold detector located between the combined 12-acceleration-gate output and the displays. The threshold may then be set sufficiently high that only occasional noise peaks trigger the threshold, and noise is then not likely to be cumulative.

RESULTS

Initially, the results of signal analysis by the acceleration-gate system were shown as indicated in Fig. 10, which is an analysis of OTH returns from an A2 Polaris missile. The analysis here was performed in nonreal time—in fact, a 20-second interval of magnetic tape data was "locked" on the storage drum by first recording, then cutting off both record and erase pulses. The stored information was continually read out with non-destructive readout. The acceleration was manually adjusted to match that of the target in a single acceleration channel, and the displays were photographed. The top photograph shows the analyzer output amplitude (shown vertically) vs doppler frequency, increasing from right to left along the abscissa. The top view shows the output for zero acceleration (constant velocity), and a test signal of constant doppler frequency is seen. The bottom view shows the output for the same input but with an acceleration slope that matches the target acceleration. The center view is an expanded version of the lower view. An appreciable gain in target amplitude was obtained, as well as excellent velocity resolution; the lower photographs show this signal as it appeared on the three main displays of velocity-range, acceleration-range, and acceleration-velocity. A series of readouts performed for a succession of time periods showed a regular stepping of the velocity, as the acceleration would indicate. But these displays depend upon the operator's memory to put together the time sequence of signals.

A more meaningful display, of a Saturn missile launched from Cape Kennedy, is shown in Fig. 11. This readout was performed at a real time rate from a magnetic tape recording of the receiver output made during the event. The 12 acceleration gates were adjusted for a fan of consecutive accelerations. The radar operating frequency was 26.6 Mc, so illumination was direct rather than OTH. The prf was 180 cps, and velocity foldover occurred at approximately 1000 knots. One complete acceleration and velocity analysis was performed each 1.7 seconds—the time interval between readout dots on a horizontal line. The top view is the output for positive accelerations, and a track beginning at about 200 seconds is the Saturn powered second stage and continues to about the point of velocity foldover. This same track continues to about 240 seconds on the center view, which is the output for a negative fan of accelerations. In this case the fan was

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DISPLAY NO. 1

DISPLAY NO. 2

DISPLAY NO. 3

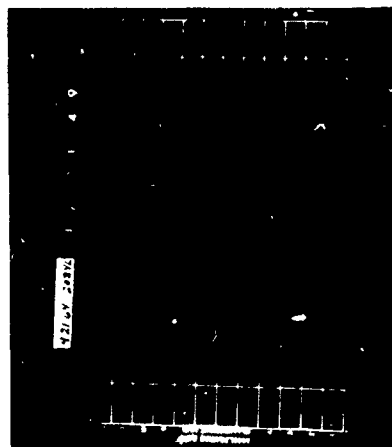
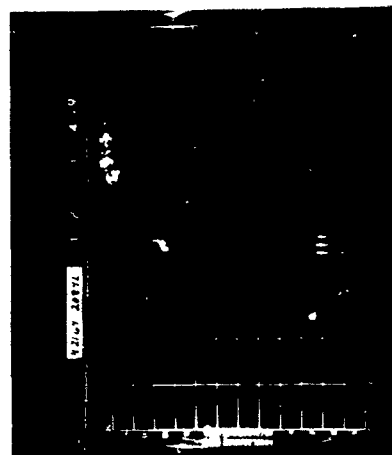
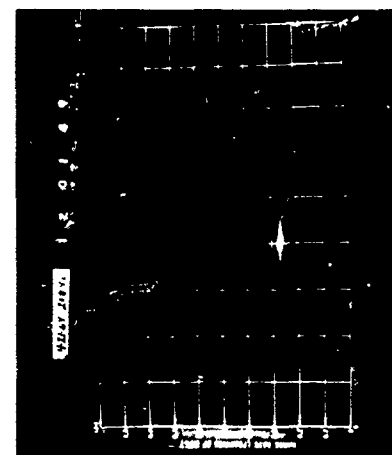


Fig. 10 - Acceleration-gate system displays of range-rate vs range (display 1), acceleration vs range (display 2), and acceleration vs range-rate (display 3). The terminal time of the 20-second stored signal readout is $T + 100$ sec. The signals on the displays were enhanced by matching the target signal with a positive acceleration functions. The upper view shows the analyzer output vs range-rate (increases from right to left) for the indicated conditions.

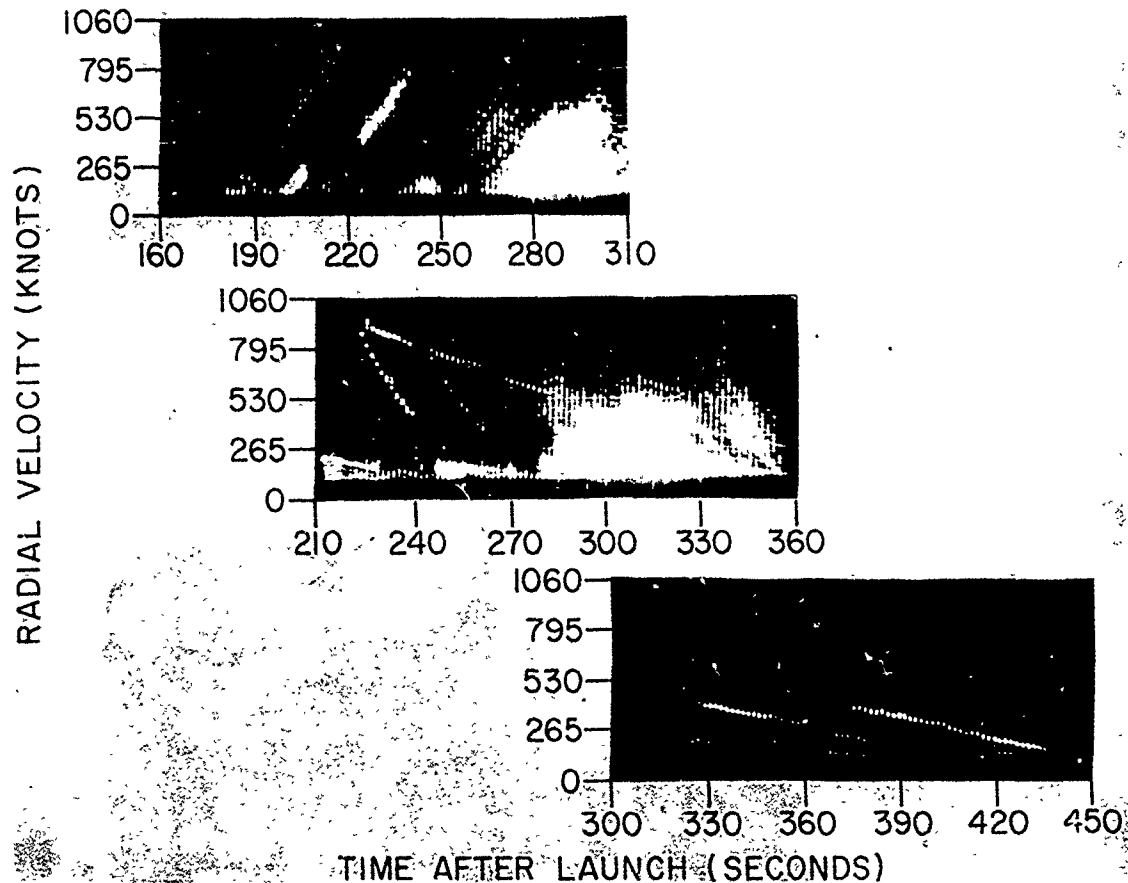


Fig. 11 - Radial velocity vs time after launch for saturn missile launched from Cape Kennedy (ETR 0169)

split to allow readout of the spent first stage on the same display. That signal is shown from just below velocity foldover at 225 seconds and continues the full time period of this photograph. Other tracks believed to be missile related are not identified, but in the top view the positive slope bordering the diffuse signal is again the second stage during powered flight. In the lower view additional filtering restricted the doppler bandwidth to about 1/2 of that shown in the upper two photographs. Other readjustments allowed the discrete track to be clearly displayed during the diffuse signal region. The last long track is an aircraft in the process of performing a turn to introduce an acceleration component. This aircraft was tracked across the full-time extent of these photos when lower value accelerations, including zero acceleration, were used.

The top view of Fig. 12 shows the calculated values of radial velocity plotted against time after launch for values of target position received from postflight information. Also shown are data points replotted from the previous figure. The lack of exact agreement between the two figures may be partially due to assumptions made in the calculations. The lower plot is a ray path diagram showing ray elevation angles with respect to the first and second stage trajectories. Numbers along the trajectory represent seconds after launch time.

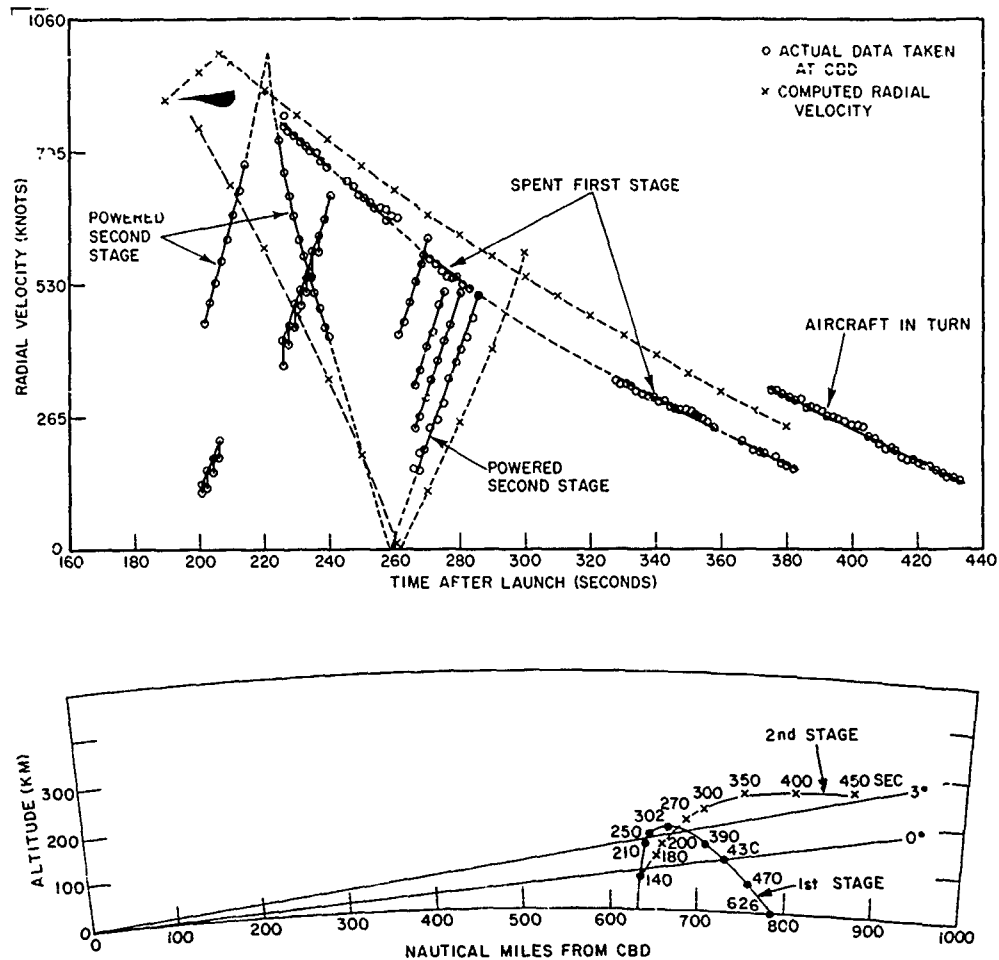


Fig. 12 - Saturn launch (ETR 0169) (a) computed radial velocity vs time after launch (b) altitude vs range from CBD

Many other missile launches from Cape Kennedy have been observed, and when it is possible to illuminate the area of the missile trajectory, signal tracks are normally obtained. Figure 13 is an OTH detection of an A3 Polaris. The upper photo was a real-time observation; the lower two were reruns later performed at real-time rates. The lower left view is a positive acceleration readout; the lower right is a negative readout with the same set of slopes as used in the upper photograph. Some loss occurred in the rerun, but a definite track was observed on the rerun that had not been seen on the original because that time interval was not initially viewed. Figure 14 shows a plot of calculated values of velocity that could be expected from the ray-path geometry from CBD. Notice the zero velocity at 145 seconds, typical for a right angle intersection of the missile flight path and illuminating ray path. The replotted points from the photograph agree, quite closely, with the calculations in this case. Other tracks which occur at re-entry body (REB) separation are not positively identified, but several parts are known to be separated from the missile at that time. Other tracks might be related to the first stage and to the nose cone jettison.

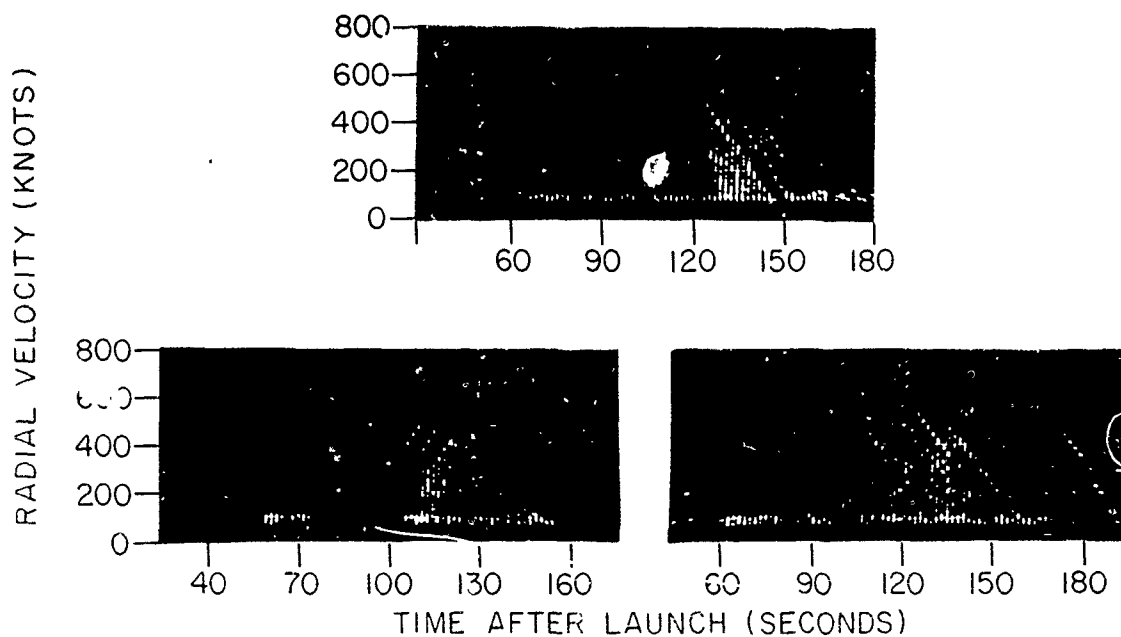


Fig. 13 - Radial velocity vs time after launch for A3 Polaris launched from Cape Kennedy (ETR 6075)

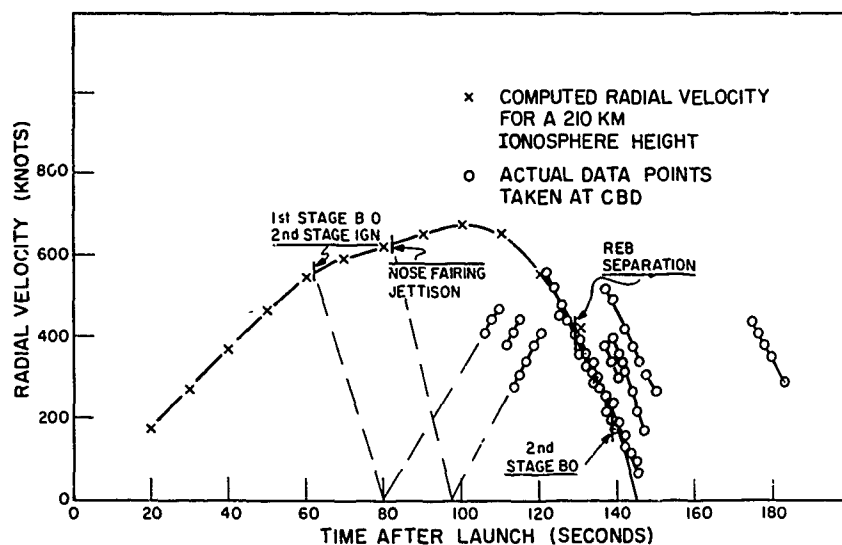


Fig. 14 - Computed radial velocity for a 210-km ionosphere height (ETR 6075)

Similar target tracks were obtained from other observations. Figure 15 gives results of an observation of an A2 Polaris launched along the Eastern Test Range (ETR) and viewed OTH from CBD. The operating frequency was 15.595 Mc. The positive track is not discrete, and the negative tracks are very distinct. A double negative track occurs at REB separation. The last track is the dead first stage. The plot of the velocity calculations and the replot of photographic data are shown on Fig. 16 and indicate a measure of comparison with each other.

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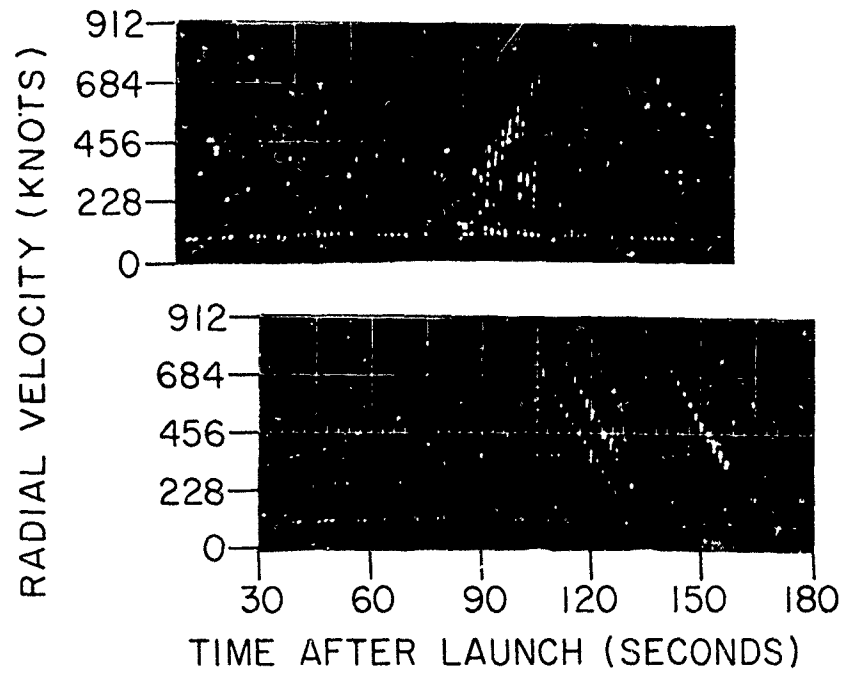


Fig. 15 - Radial velocity vs time after launch
for an A2 Polaris (ETR 2949)

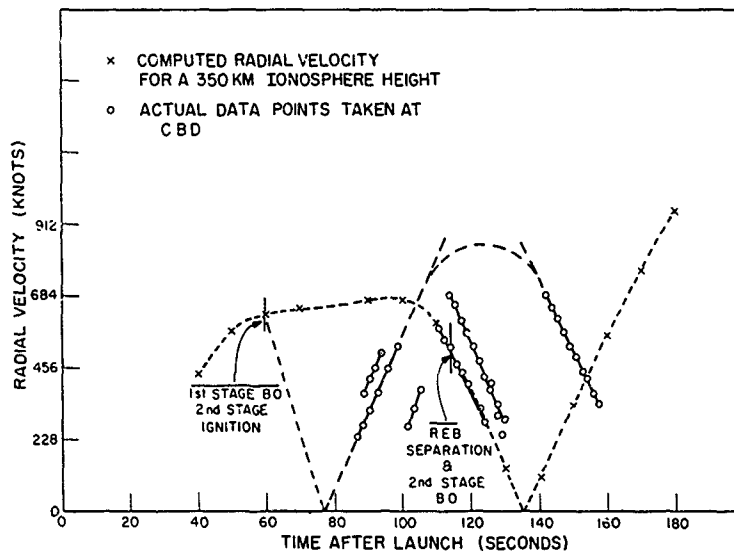


Fig. 16 - Computed radial velocity for a 350-km
ionosphere height (ETR 2949)

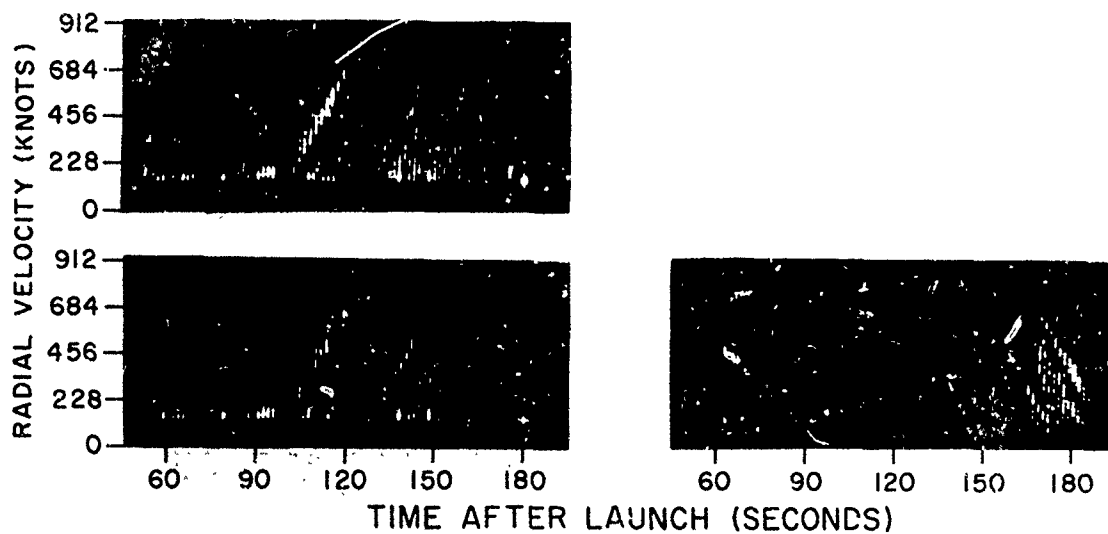


Fig. 17 - Radial velocity vs time after launch for a Minuteman (ETR 0351)

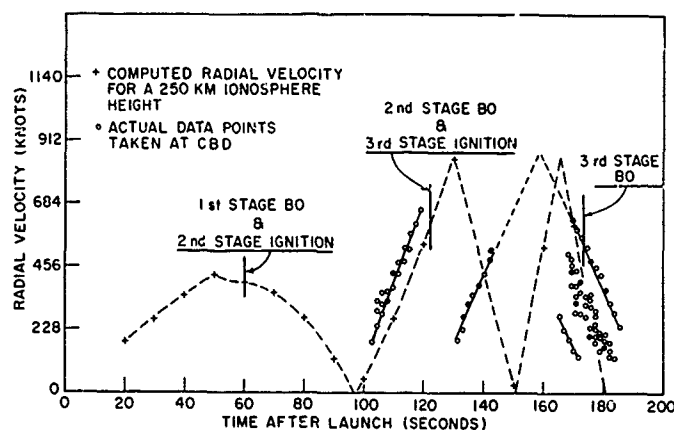


Fig. 18 - Computed radial velocity for a 250-km ionosphere height (ETR 0351)

Several Minuteman launches from the ETR have been viewed OTH from CBD. One of these is Test 0351 which is shown on Fig. 17. One velocity track with positive acceleration occurs at about 105 seconds after T-0, which is during the period of second stage burning. Other missile-related velocity tracks occur later. The calculation from post-flight position and velocity data and a replot of these photographic data are shown on Fig. 18. A good agreement is reached for the second stage interval, while other tracks are not positively identified.

Other target detections and velocity time tracks have been obtained at longer ranges. Several are results from the White Sands Missile Range (WSMR). The results of one of these WSMR tests are shown in Fig. 19. The target is an Athena missile and was viewed at a range in excess of 1600 naut mi.

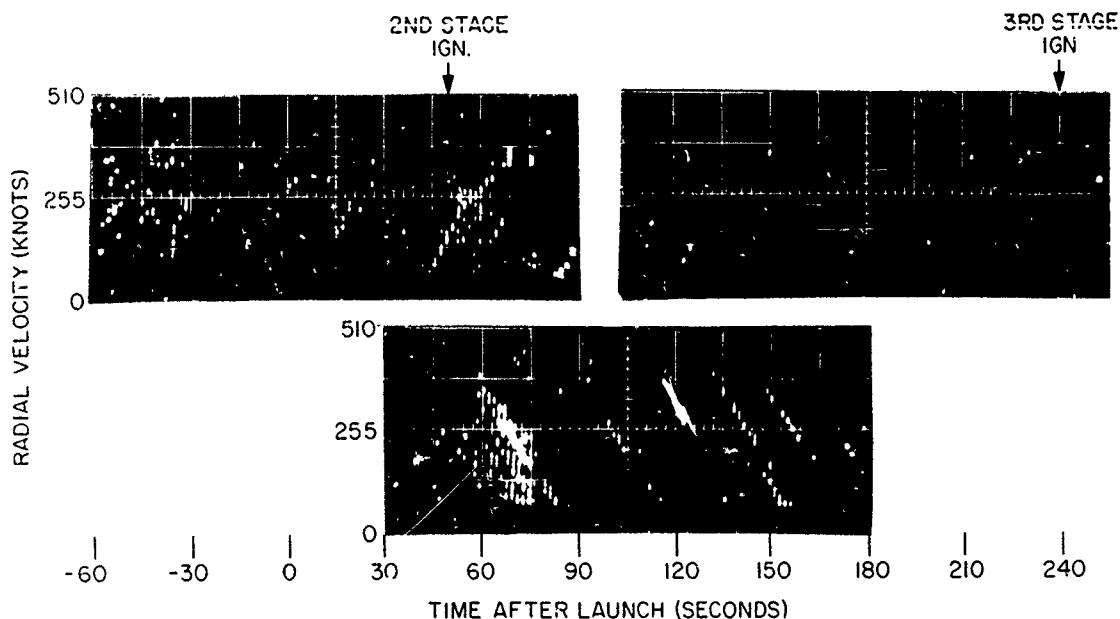


Fig. 19 - Radial velocity vs time after launch (WSMR 021-C005-B06)

Photographs of the limited, 12-acceleration-gate system, as implemented at CBD, are shown in Figs. 20 and 21. Figure 20 shows the signal simulator contained in the first two racks, followed by the acceleration function generator, the oscillator, and the analyzer racks. All are double sided and each of the last three provides 12 separate chassis, one for each channel. The mobile oscilloscope is used to display the actual oscillator frequency sweep and shows the combined effect of both the velocity and the acceleration modulations. Figure 21 shows the electronic commutator, sweeps and step generators for sweep drive and timing, the three main displays, and additional power supplies. Camera mounts for single-framed 16mm movies, plus Polaroid cameras, are provided for each display.

SIGNIFICANCE AND ADVANTAGES OF ACCELERATION PROCESSING

A number of advantages are gained by the use of an acceleration and velocity signal processor.

1. The same high S/N processing gains are obtained for small accelerating targets as could normally be obtained for only constant velocity targets in a simple doppler analyzer.
2. High velocity-and-acceleration resolution is provided for either small or large amplitude returns from accelerating targets.
3. Acceleration is available as a system parameter.
4. Accelerating targets may be separated from constant-velocity targets and viewed on separate displays. This procedure allows the separation of most aircraft and meteors from the missile displays but still retains the information on a constant-velocity display.

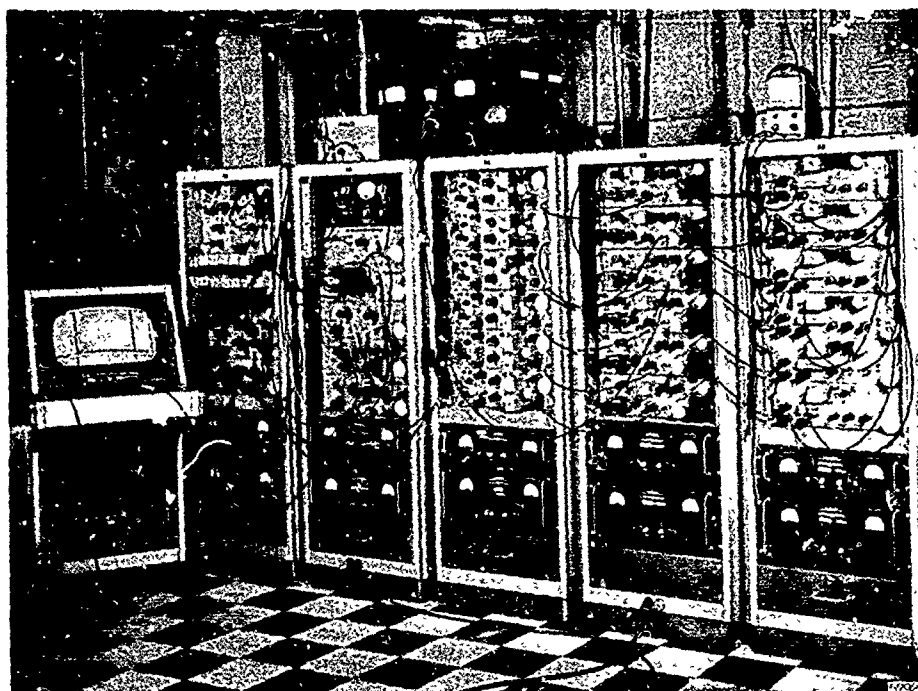


Fig. 20 - Acceleration-gate system - racks 1 through 5

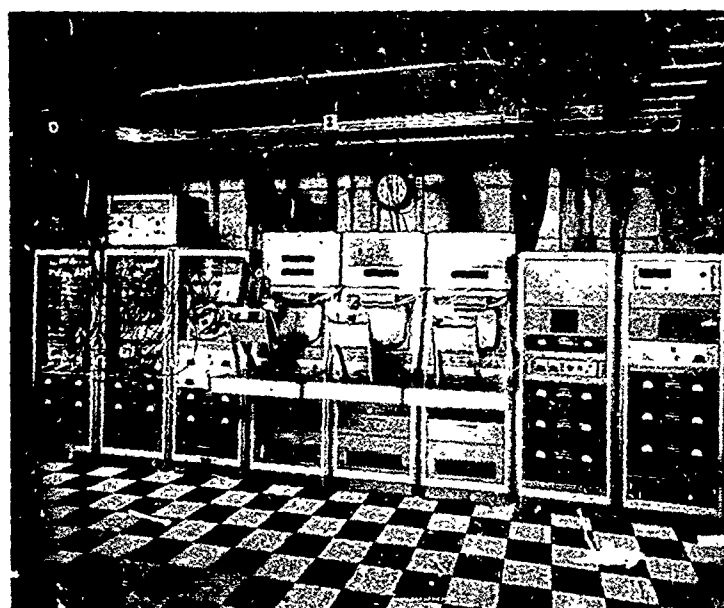


Fig. 21 - Acceleration-gate system - racks 6 through 13

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(This separation is somewhat analogous to the method where fixed and low-velocity targets, including backscatter, are separated from the velocity display.)

5. Well-defined target-velocity-vs-time tracks are provided which may be separated from diffuse signals and separately displayed.

CONCLUSIONS

It has been demonstrated that, first, significant losses of both S/N and velocity resolution are caused as a direct result of target acceleration in a hf, pulse-doppler radar that performs coherent integration for long signal integration periods, and, second, that this acceleration-caused loss may be mainly eliminated by the acceleration processing technique of spectral compression.

Results of operating a limited 12-acceleration-gate system have been favorable and indicate that a full real-time acceleration and velocity signal processor would be highly desirable for an operational hf, OTH, pulse-doppler radar.

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates) An interim report on a continuing problem		
5. AUTHOR(S) (First name, middle initial, last name) J.E. McGeogh and G.K. Jensen		
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of the Air Force Rome/Air Development Center, Rome, N.Y.	
13. ABSTRACT [Secret] <p>When determining the design of the signal processor, the overall radar problem must be considered in order to achieve optimum radar performance. The choice of a signal processor type for a high-frequency, over-the-horizon, pulse-doppler radar is particularly important because it must perform maximum signal enhancement to detect and observe very small signals buried in noise and, simultaneously, extract the maximum target information. Although many factors influence the design, this report is primarily concerned with the effect of target acceleration on the performance of the signal processor. Since targets of interest include guided missiles as well as aircraft, provision for acceleration and velocity processing should be included to insure that maximum sensitivity and velocity resolution will be available for both accelerating and constant velocity targets.</p> <p>Examination was made of how target acceleration degrades performance in a simple velocity analyzer and also the method of providing essentially maximum sensitivity and velocity resolution for accelerating targets by an acceleration processing technique of spectral compression. Actual results obtained with a limited, 12-acceleration gate, acceleration and velocity signal processor confirm that full system sensitivity and velocity resolution are provided for accelerating and constant velocity targets.</p> <p>Abstract continues</p>		

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Signal-to-noise ratio Acceleration and velocity processing Signal processor High-frequency radar						
<p>In considering the advantages made possible by inclusion of acceleration processing, it is concluded that an acceleration and velocity signal processor using the spectral compression technique is highly desirable for a high-frequency, over-the-horizon, pulse-doppler radar.</p>						

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Naval Research Laboratory. Report 6611
[SECRET-Gp-3]. ACCELERATION AND VELOCITY
PROCESSING OF HF RADAR SIGNALS [Unclassified
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processing
2. Radar
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In considering the advantages made possible by inclusion of acceleration processing, it is concluded that an acceleration and velocity signal processor using the spectral compression technique is highly desirable for a high-frequency, over-the-horizon, pulse-doppler radar. [Secret Abstract]

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MEMORANDUM

20 February 1997

Subj: Document Declassification

Ref: (1) Code 5309 Memorandum of 29 Jan. 1997
(2) Distribution Statements for Technical Publications
NRL/PU/5230-95-293

Encl: (a) Code 5309 Memorandum of 29 Jan. 1997
(b) List of old Code 5320 Reports
(c) List of old Code 5320 Memorandum Reports

1. In Enclosure (a) it was recommended that the following reports be declassified, four reports have been added to the original list:

Formal: 5589, 5811, 5824, 5825, 5849, 5862, 5875, 5881, 5903, 5962, 6015, 6079, 6148, 6198, 6272, 6371, 6476, 6479, 6485, 6507, 6508, 6568, 6590, 6611, 6731, 6866, 7044, 7051, 7059, 7350, 7428, 7500, 7638, 7655. Add 7684, 7692.

Memo: 1251, 1287, 1316, 1422, [REDACTED], 1500, 1527, 1537, 1540, 1567, 1637, 1647, 1727, 1758, 1787, 1789, 1790, 1811, 1817, 1823, 1885, 1939, 1981, 2135, 2624, 2701, 2645, 2721, 2722, 2723, 2766. Add 2265, 2715.

The recommended distribution statement for the these reports is: **Approved for public release; distribution is unlimited.**

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J. M. Headrick
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